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A Study of Heat Load for the 6.5 T SWLS at the Siam Photon Source

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Abstract

The Siam Photon Source (SPS) is a 1.2 GeV, 2nd generation SR that was designed to use bending magnets as the primary source, until one insertion device, which is an undulator, was installed. Recently an upgrade project funding for two more insertion devices was provided, which are a 2.4 T hybrid wiggler from ASTec and a 6.5 T SWLS donated from NSRRC. This report will present the mechanical design of the vacuum chambers and the cooling absorber components, which has to handle the radiation power of 1.9 kW emitted by the SWLS during operation at 200 mA.

Introduction

The Siam Photon Source (SPS) is a 1.2 GeV synchrotron radiation source located in Nakhon Ratchasima, Thailand. The accelerator complex consists of a 0.5 Hz, 1.0 GeV injector and a 1.2 GeV storage ring. The electron storage ring has four 7 m long straight sections, where two of them are partly occupied by an injection septum and a RF cavity. A permanent magnet planar undulator was installed at a third straight section [1]. For the last straight section the installation of a 6.5 T wavelength shifter (SWLS) is planned for 2013. The 2.4 T hybrid wiggler will be installed in the same straight section as the injection septum.

The SWLS contains a compact three-pole superconducting magnet. Three pairs of NbTi superconducting wire coils are connected to one main power supply to create a central magnetic field of 6.5 T. The superconducting magnet is installed into a cryostat, which uses a liquid helium bath of 250 liter to cool down the magnet. A thermal shield supported by a liquid nitrogen tank of 15 l volume helps to keep the liquid helium consumption rate low. The diameter of the SWLS and its cryostat is 600 mm. The electrons are passing the SWLS through a warm beam duct made of aluminum with a racetrack-shaped aperture of 113 mm (horizontal) x 20 mm (vertical) [2].

During operation the electron beam will be charged with high energy through the superconducting magnet in accordance to produce the desired hard x-rays. In order to prevent excessive heating of components, the downstream vacuum chambers have to be equipped with a cooling system.

Heat load on vacuum chamber components

The heat load on the vacuum chamber components was obtained from the energy distribution of the synchrotron radiation of the SWLS. The total power distribution at 1.2 GeV and 200 mA is shown in figure 1. The synchrotron radiation source point of the central pole is offset 11.2 mm from the magnet center. The total power of 1.9 kW is emitted in a fan with a horizontal aperture of ± 85.5 mrad. The factor $1/\gamma$ was used to calculate the radiation spread for the vertical direction, which in the case of the SPS storage ring is ± 0.4 mrad.

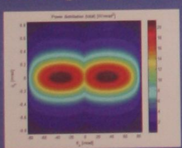

Fig. 1: Total power distribution of the SWLS

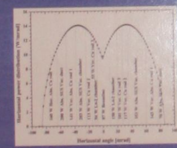

Fig. 2: Horizontal power distribution

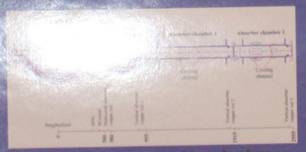

Fig. 3: Vacuum components and heat absorbers downstream of the 6.5 T SWLS

Figure 2 gives an overview over the horizontal power distribution with the total heat load on various areas downstream the vacuum chamber. In order to prevent material deformation and heat damages on the vacuum chamber components, water cooled heat absorbers are attached at different locations [3]. Two different types of heat absorbers were designed. The first type is an absorber copper rod with internal water cooling. The first absorber copper rod is horizontally disposed and is located directly behind the SWLS downstream. The other absorber copper rods are vertically disposed.

The second absorber type consists of two cooling water channels, which are attached on both sidelines of the stainless steel pumping duct and the absorber chambers 1 and 2. Figure 3 shows the location of all heat absorbers.

Conclusion

Components downstream the 6.5 T SWLS are exposed to a high heat load due to the high energy of the synchrotron radiation. Cooling absorbers were designed to protect the parts from overheating and deformation. The heat load on every component was obtained and the convection coefficient α for the water cooled absorber elements was calculated. FEM software was used for thermal and static studies to ensure that no overloading of parts occurs and for the optimization of the absorber design.

Reference

[1] P. Klysubun, S. Rugmai, S. Cheedket, P. Sudmuang, G. Hoyes, M. Oyamada, W. Pairsuwan, "Present Status Of The Siam Photon Source", Proceedings of EPAC'08, Genoa, Italy, p.2061 (2008)

[2] C. S. Hwang, B. Wang, B. Wahrer, C. Taylor, C. Chen, T. Juang, F. Y. Lin, J. C. Jan, C. H. Wang, H. H. Chen, M. H. Huang, K. T. Hsu and G. Y. Hsiung, "Design, Construction, and Performance Testing of a 6.5 T Superconducting Wavelength Shifter", IEEE Trans. on Appl. Supercond., 17 (2), p.1229 (2007)

[3] D. Berger, H. Krauser, M. Rose, V. Duerr, E. Weihreter, S. Reul, "Mechanical And Thermal Design Of Vacuum Chambers For A 7 T Mulitpole Wiggler For Bessy II", Proceedings of EPAC'02, Paris, France, p.2598 (2002)

[4] Günter Cerbe, Hans-Joachim Hoffmann, "Einführung in die Thermodynamik", 12. Aufl., Carl Hanser Verlag München Wien, 1999

FEM-Simulation of the heat loads on vacuum chamber components

To investigate the influence of the heat load caused by the high energy synchrotron light 3D models of the absorber components were designed. The finite element method (FEM) was used for the thermal simulations applied on simplified models. Contact surfaces, where the radiation beam is contacting the copper rods respectively the pumping duct and the absorber chamber 1, were defined. Absorber chamber 2 and the vertical absorber copper rods 3 were not analyzed, because these components are exposed to a lower heat load in comparison to other parts.

For the simulation process the heat load [Watt] was applied on the defined contact surfaces. The convection of the water cooling was considered by using the convection coefficient α. This coefficient can be calculated with the following equation [4]:

$$\alpha = \frac{Nu \cdot \lambda}{d}$$

(Nu = Nußelt number; λ = heat conduction coefficient of the cooling water; d = inner pipe diameter)

The Nußelt number can be calculated by using the formula for forced flow inside a pipe referred to Hausen and Gnielinski:

$$Nu = 0.012\left(Re^{0.87} - 280\right)Pr^{0.4}\left[1 + \left(\frac{d}{l}\right)^{\frac{2}{3}}\right]K$$

(Re = Reynolds number; Pr = Prandtl number; d = inner pipe diameter; l = pipe length; K = influence of temperature dependant material values)

Due to the difficult prediction of the water flow inside the cooling components concerning laminar or turbulent flow, fluid velocity etc. the calculated value for the convection coefficient α was divided by a safety factor of 2. For the thermal simulations α-values between 1500 W/m²K and 2860 W/m²K (depending on the length and geometry of the components) were used. Table 1 gives an overview of the investigated components, the input parameters for the FEM software and the results of the simulations.

No.	Component	Heat Power [W]	Convection coefficient α [W/m²K]	Beam contact area W x L [mm]	Temperature [°C]	Displacement [mm]
1	Horizontal absorber copper rod	160	2750	0.5 x 26	140.2	
2	Absorber at SUS vacuum pumping duct	200 resp. 70	1500	0.67 x 172	120.6	0.1
3	Vertical absorber copper rod 1	143	1540	0.75 x 20	91.4	
4	Vertical absorber copper rod 2	117	2860	1.59 x 24	79.2	
5	Absorber at SUS vacuum chamber	353 resp. 203	1500	1.23 x 695	60.1	0.11

Table 1: List of the investigated vacuum chamber components with input parameters for the FEM software and the results of the simulations

The FEM simulation shows that the horizontal absorber copper rod (No. 1), which is the closest absorber to the SWLS, heats up the most (fig. 4). The temperature rises up to 140.2 °C, which is within a reasonable range, due to the much higher melting point of copper and stainless steel (SUS) and the ability of these materials to have sufficient strength durability at the simulated temperature. The vertical absorber copper rods (No. 3 and 4) are exposed to lower temperatures, so that no problems with these parts are expected (fig. 5).

Fig. 4: Thermal simulation of the horizontal absorber copper rod

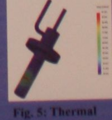

Fig. 5: Thermal simulation of the vertical absorber copper rod

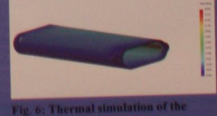

Fig. 6: Thermal simulation of the absorber at the SUS vacuum chamber 1

Fig. 7: Displacement simulation of the SUS vacuum chamber 1

Furthermore the simulation results show that the absorber at the SUS pumping duct (No. 2) heats up to 120.6 °C. The elevated temperature leads to an expansion of 0.1 mm in longitudinal direction. The pumping duct has a total length of 300 mm. An expansion of 0.11 mm was simulated for the SUS absorber chamber 1 (No. 5), although the temperature only rises up to 60.1 °C (Fig. 6 and 7). This can be explained by the long length (825 mm) of the absorber chamber 1. The expansions in longitudinal direction for the pumping duct and the absorber chambers 1 and 2 will be compensated by bellows that are attached at one end of each part.

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